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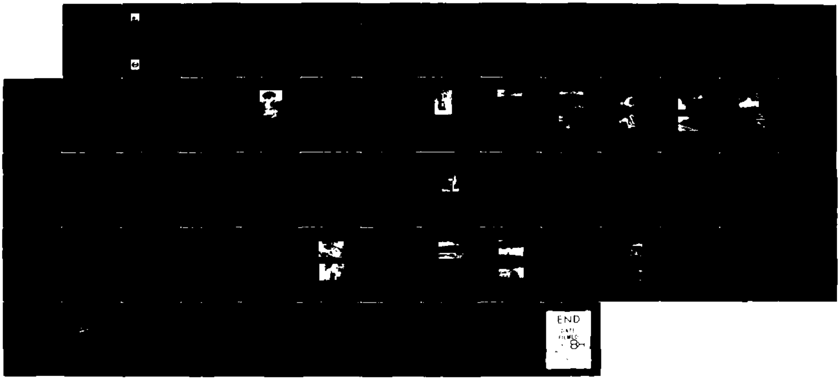

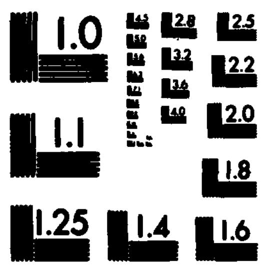

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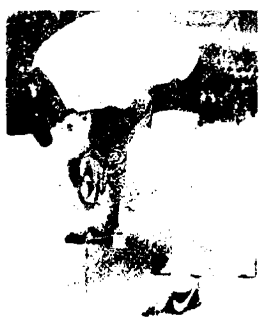
TECHNICAL REPORT EL-87-15

PHYSICAL EFFECTS OF BEACH NOURISHMENT ON SEA TURTLE NESTING, DELRAY BEACH, FLORIDA



by

David A. Nelson

Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

Karen Mauck

The Discovery Center, Museum of Science, Art, and History
231 S.W. Second Avenue, Fort Lauderdale, Florida 33301

and

John Fletemeyer

Nova University
Fort Lauderdale, Florida 33301

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A large percentage of all sea turtle nests in the United States are located in beaches that have been nourished or renourished. Questions have been raised about how physical changes in the beaches will affect the nesting activities of these sea turtles that use nourished beaches for nesting. This study was conducted to examine the physical changes in a beach from prior to nourishment in 1984 to after nourishment in 1985 at Delray Beach, Fla., and the response of nesting turtles to those changes. Two beaches, one north and one south of the project area, were studied as references.

Delray Beach had a harder consistency from both previous nourishments and the 1984 renourishment. The cause of the harder consistency is unclear. However, finer grain size, layering of sand grains, the cohesion of silt-clay particles, equipment operation on the beach, and weight of the sand-water slurry from the hydraulic pumping are probable contributors to a harder consistency. Effects of nourishment on nesting loggerhead turtles

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6c. ADDRESS (Continued).

PO Box 631
Vicksburg, Mississippi 39180-0631

231 S. W. Second Avenue
Fort Lauderdale, Florida 33301

Fort Lauderdale, Florida 33301

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include: (1) eggs and hatchlings were not affected negatively by the nourished sand; (2) nest depth and frequency of false digs may be affected by the harder consistency, but this effect was not evident in this study; (3) nest shape and nest digging time may be affected by sand consistency; (4) the number of nests per emergence appears to have declined following the nourishment; (5) aragonite sand may negatively affect piping hatchlings; and (6) a scarp formed at Delray Beach and will form at most beaches. The scarp may block some turtles from nesting, while some may scale the scarp, particularly if the scarp is sloped.

Preface

This report was sponsored by the US Army Engineer District, Jacksonville, and the Office, Chief of Engineers (OCE), US Army, as part of the Environmental Impact Research Program (EIRP), Work Unit 31533, entitled Beach and Foredune Ecology. The Technical Monitors for the study were Dr. John Bushman and Mr. Earl Eiker of OCE and Mr. David B. Mathis, Water Resources Support Center. The field studies and preparation of a draft final report were accomplished during the time period April 1984 to September 1986.

This report was prepared by Mr. David A. Nelson, Coastal Ecology Group (CEG), US Army Engineer Waterways Experiment Station (WES); Mrs. Karen Mauck, The Discovery Center, Fort Lauderdale, Fla.; and Mr. John Fletemeyer, Nova University, Fort Lauderdale, Fla. Mr. Nelson was principal investigator for this report, under the general supervision of Mr. Edward J. Pullen, Chief, CEG; Dr. Conrad J. Kirby, Jr., Chief, Environmental Resources Division; and Dr. John Harrison, Chief, Environmental Laboratory, WES. Dr. Roger Saucier, WES, was Program Manager of EIRP. The report was edited by Ms. Lee T. Byrne Information Products Division, Information Technology Laboratory, WES.

The following are gratefully acknowledged for their assistance in the design of this study: Dr. Jon Moulding, US Army Engineer District, Jacksonville, Fla.; Mr. Dave Smith, US Fish and Wildlife Service (ES), Vero Beach, Fla., and Mr. Ross Witham, Florida Department of Natural Resources, Jensen Beach, Fla. Also acknowledged are Mr. Scott Schellhauss and Ms. Carol Mayes, CEG, and Messrs. Ed Hands and Mark Hansen, Coastal Engineering Research Center, for assistance in gathering field data. Mr. James Giles assisted with data entry, and Ms. Virginia Sotler, CEG, assisted with data analysis. Appreciation is extended to the City of Delray Beach for permission to monitor their beach and to use information from their turtle hatchery program.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is the Technical Director.

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Contents

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Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms

PHYSICAL EFFECTS OF BEACH NOURISHMENT ON SEA TURTLE NESTING, DELRAY BEACH, FLORIDA

Background

1. A large percentage of all sea turtle nests in the United States are located in beaches that have been nourished or renourished. Questions have been raised about how physical changes in beaches will affect the nesting activities of these sea turtles (Ehrhart and Raymond 1983). This study was conducted to examine the physical changes in a renourished beach at Delray Beach, Florida, and the response of nesting sea turtles to those changes.

Nesting loggerhead turtles

2. On Hutchinson Island, Florida, loggerhead turtles begin nesting in the spring when local water temperatures begin to reach 23° to 24° C (Williams-Walls et al. 1983). Nesting increases with rising temperatures and photoperiod to peak in June and July; then nesting activity declines until completion of the nesting season in late summer (August-September) (Fletemeyer 1981, 1982, 1983a, 1983b; Stoneburner 1981; Richardson and Richardson 1982).

3. Loggerhead females generally nest every other year or every third year, although a small percentage nest at intervals less than 2 or more than 3 years (Richardson and Richardson 1982; Bjorndal, Meylan, and Turner 1983; Ehrhart and Raymond 1983; Fletemeyer 1983a). When a loggerhead nests, it will usually lay two to three clutches (range, one to five) of eggs per season (Ehrhart 1979; Talbert et al. 1980; Fletemeyer 1981; Richardson and Richardson 1982). These interseasonal nestings are generally 12 to 14 days apart (range, 11 to 20 days) (Fletemeyer 1983a; Williams-Walls et al. 1983). The distance between nest sites (renesting distance) of a particular turtle during a season is generally less than 5 km (Hughes 1974; LeBuff 1974; Ehrhart 1979; Talbert et al. 1980; Fletemeyer 1983a; Williams-Walls et al. 1983). Loggerheads are considered to be less site specific when returning to their nests both between and within seasons than green turtles (Caldwell, Carr, and Ogren 1959; Talbert et al. 1980; Bjorndal, Meylan, and Turner 1983).

4. The selection of a beach for nesting may be based on nest site fixity (Carr 1967, Richardson and Richardson 1982, Fletemeyer 1983a, Hopkins and Richardson 1984), learned behavior (Hendrickson 1958), position of beach rocks

(Hughes 1974, Mann 1978), and proximity of offshore reefs (Stoneburner 1982). Loggerheads may return to a beach to nest because of imprinting to that particular beach (nest site fixity) (Carr 1967) or through social facilitation by following other nesting females to the nesting beach (Hendrickson 1958). Rock outcrops on the shoreline may serve to guide turtles to a certain beach (Hughes 1974), or when the rocks are narrowly spaced, they may reduce the use of a beach for nesting (Mann 1978). Beaches in close proximity to offshore reefs are used more frequently for nesting. These reefs are used by the turtles for resting and feeding areas between egg-laying sessions (Stoneburner 1982, Williams-Walls et al. 1983).

5. Loggerheads emerge from the surf at night and crawl ashore. Approximately 30 to 40 percent of the time when loggerheads crawl onto the beach, they return to the water without depositing eggs (false crawls) (Stoneburner 1981, Ehrhart and Raymond 1983, Williams-Walls et al. 1983). The process of a turtle's excavating a cavity without laying eggs is referred to as a false dig. The reason for these false crawls and false digs is not well understood, but they probably are influenced by a turtle's "readiness" to lay, physical properties of the beach, temperature of the beach sand, and disturbance of the emerging turtles (Mann 1978, Fletemeyer 1981, Stoneburner and Richardson 1981, Ehrhart and Raymond 1983). Sand with too firm a consistency may inhibit or prevent turtles from digging nests (Fletemeyer 1981, Ehrhart and Raymond 1983, Williams-Walls et al. 1983). Emerging turtles that encounter human or animal activity or lights shining directly onto the beach may return to the water without nesting (Mann 1978, Fletemeyer 1979, Ehrhart and Raymond 1983). Moving lights such as from automobiles may also deter nesting in some locations (Mann 1978).

6. Loggerheads usually locate their nests between mean high tide and the top of the primary dune. Each female turtle may make one to four false digs before finally laying eggs in one cavity (Ehrhart and Raymond 1983). The digging of a nest and egg-laying usually take about 1 hr. Between 35 and 180 eggs (mean, 120 eggs) are deposited into the nest hole (Fletemeyer 1983a, Hopkins and Richardson 1984). The nest site has a very shallow depression (body pit). The depth of the flask-shaped nest from the beach surface to the bottom of the eggs ranges from 43 to 86 cm (mean, 58.7 cm). The vertical thickness of the egg mass ranges from 10 to 40 cm (mean, 23 cm) (Limpus, Baker, and Miller 1979). The nest cavity is 20.3 to 25.4 cm wide (Caldwell 1959). The

depth from the beach surface to the top of the eggs ranges from 12.7 to 55.9 cm, but most often this depth is 27.9 to 40.6 cm.

Nesting turtle response
to change in sand consistency

7. The response of a turtle to a change in sand consistency can be measured directly by observation of the turtle's digging activity or indirectly by measuring the consistency of the sand at sites where turtles have successfully (a nest) or unsuccessfully (a false dig) dug nest cavities. Direct observation of the effects of sand consistency on digging turtles can be difficult and time consuming because turtles nest at night, readily abandon a nest site when disturbed, and nest at varying times and locations along a beach. Thus, turtle response to a change in sand consistency was determined indirectly by measuring shearing resistance at a digging site. Shearing resistance, a measure of the ability to penetrate the sand, is an indication of the resistance a turtle encounters when digging a nest cavity. Measurements of shearing resistance must be made adjacent to a nest cavity because a digging turtle disturbs the sand within the vicinity of the cavity.

8. While shearing resistance (consistency) is a measure of the ability to penetrate the sand, compaction is the reduction in the volume of the sand to a greater density. Shearing resistance is generally higher in more compact or denser sand; however, sands with the same density may have different shearing resistances. Shearing resistance is a result of the pressure between sand grains that is affected by grain size distribution, grain shape and orientation, and weight of overburden (Means and Parcher 1963, Griffiths 1967). Sand grains of more uniform size (poorly graded) tend to be less dense and thus less resistant to shearing (penetration) than well-graded (different-size) sand grains. Sand grains with an angular shape resist penetration (higher shear resistance) more than smooth-edged grains do. Flat-shaped (nonspherical) sand grains will resist penetration more when oriented parallel to the beach surface than when oriented at angles to the beach surface. Shear resistance is increased by the pressure of overburden material (amount/weight); thus, shearing resistance will increase with depth in the sand. Grain size gradation, grain shape, and grain orientation interact with each other to affect the density and thus the weight of the overburden.

9. Another method for examining the effects of a change in sand consistency on nesting turtles is to compare the number of nests and false digs

in the nourishment area with those in a reference area before and after the sand is deposited on the beach. An increase in the number of false digs in the nourishment area and not in the reference area indicates that the increase is a result of the disposal. However, the number of nests and false digs is relative to the number of times a turtle emerges from the water onto the beach (emergences). These emergences can be influenced by a number of physical and biological factors other than sand consistency (see nesting discussion).

Description of Delray Beach Renourishment Project

10. About 14,000 ft* of Delray Beach was renourished during September and October 1984 (Figure 1). The total volume of fill that was hydraulically pumped onto the beach was approximately 823,000 cu yd. The constructed width of the beach berm was approximately 84 ft* seaward of the erosion control line. The borrow area, approximately 2,700 ft seaward of the shoreline, was 800 ft wide by 200 ft long in water depths of 55 to 60 ft (Figure 2). The average mean grain size of the fill material was 0.22 mm (2.21 phi) (Figure 3). The beach was initially filled in 1973 and renourished in 1978. Project information is summarized in Table 1 (Strock and Associates, Inc. 1984). The north and south reference areas were 8,500 ft long and adjacent to each end of the renourished beach.

Methods

Shearing resistance

11. A cone penetrometer was used to measure the shearing resistance (penetration) of the sand (penetrability). The penetrometer had a 1.25-sq cm, 30-deg, circular cone on one end of a 45.6-cm shaft. When the cone was pushed into the sand, the proving ring was deflected in proportion to the force applied. The amount of force applied was read as a cone index value on a 0 to 750 dial.

12. The penetrometer tip was pushed into the sand with a steady, slow force until the sand surface reached the 6 in. (15.2 cm) mark on the

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4).

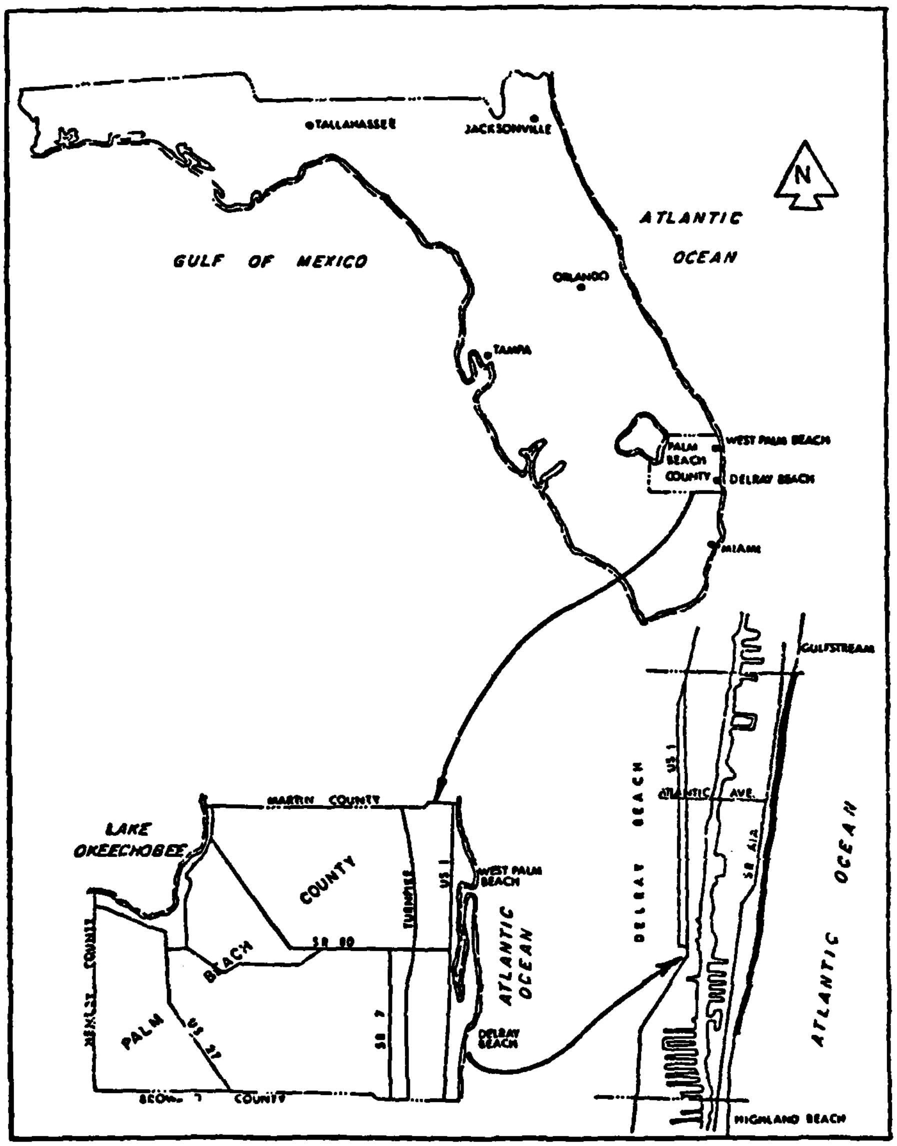


Figure 1. Location map, Delray Beach, Florida (from Strock and Associates, Inc. 1984)

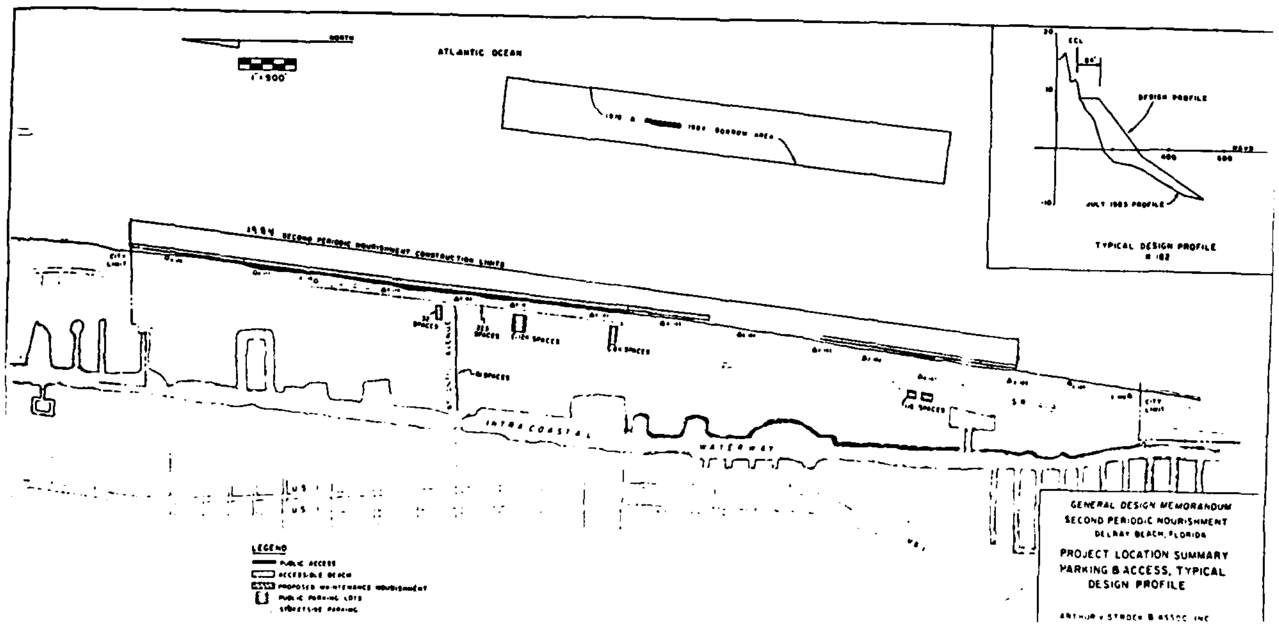


Figure 2. Project location: summary, Delray Beach, Florida (from Strock, and Associates, Inc. 1984)

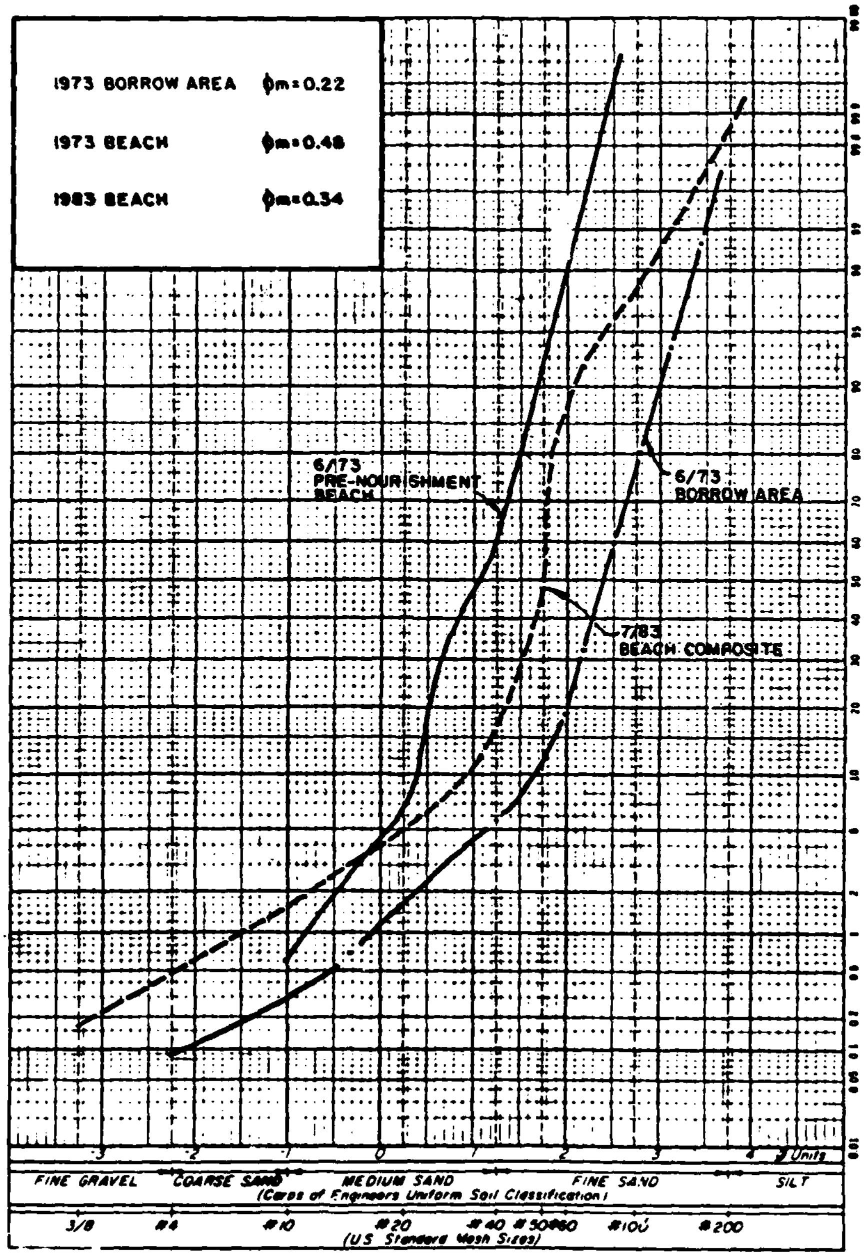


Figure 3. Delray Beach composite grain size comparison (from Strock and Associates, Inc. 1984)

Table 1

Project Comparisons*

	Authorized	1973 Initial Fill	1978 Periodic Nourishment	1984 Periodic Nourishment
Length of fill, miles	3.0	2.6	1.7	1.7
Volume of fill	1,158,000	1,634,513	700,000	823,000
Berm elevation	+10' MLW	+9' NGVD	+9' NGVD	+9' NGVD
Design slopes (beach/nearshore)	1:20/1:30	1:20/1:30	1:20/1:30	1:15/1:30
Design width at MHW, ft	100	100	100	100
Cost	$1,231,000	$2,115,164	$1,600,000	$4,230,000
Benefit/cost ratio	1.5	1.8	1.5	3.3
Federal participation, percent	3.4	44.2	44.2	43.8

* (from Strock and Associates, Inc. 1984).

penetrometer rod; then a reading was taken (Figure 4). After three readings, 6 in. (15.2 cm) of sand was removed, and three more measurements were taken at each 6-in. (15.2-cm) depth increment. The measurements were taken at depths of 6, 12, 18, 24, and 36 in. (15.2, 30.4, 45.6, 60.8, and 76.0 cm). Penetration measurements were taken for the beach at the six depths on eight transects, four within the project area and two in each of the reference transects. Each of the four transects had three stations, one at the base of the beach vegetation, one at the mean high tide, and one equidistant between the base of the vegetation and mean high tide.

13. Three measurements were taken adjacent to the turtle nests at the first three penetrometer measurement depths in the nourishment and reference areas to determine differences in shear resistances for nests in the three locations. Three measurements were taken in the bottom of each false dig.

14. Sand penetration measurements and samples were taken prior to nourishment in June 1984 and again following nourishment in October 1984.

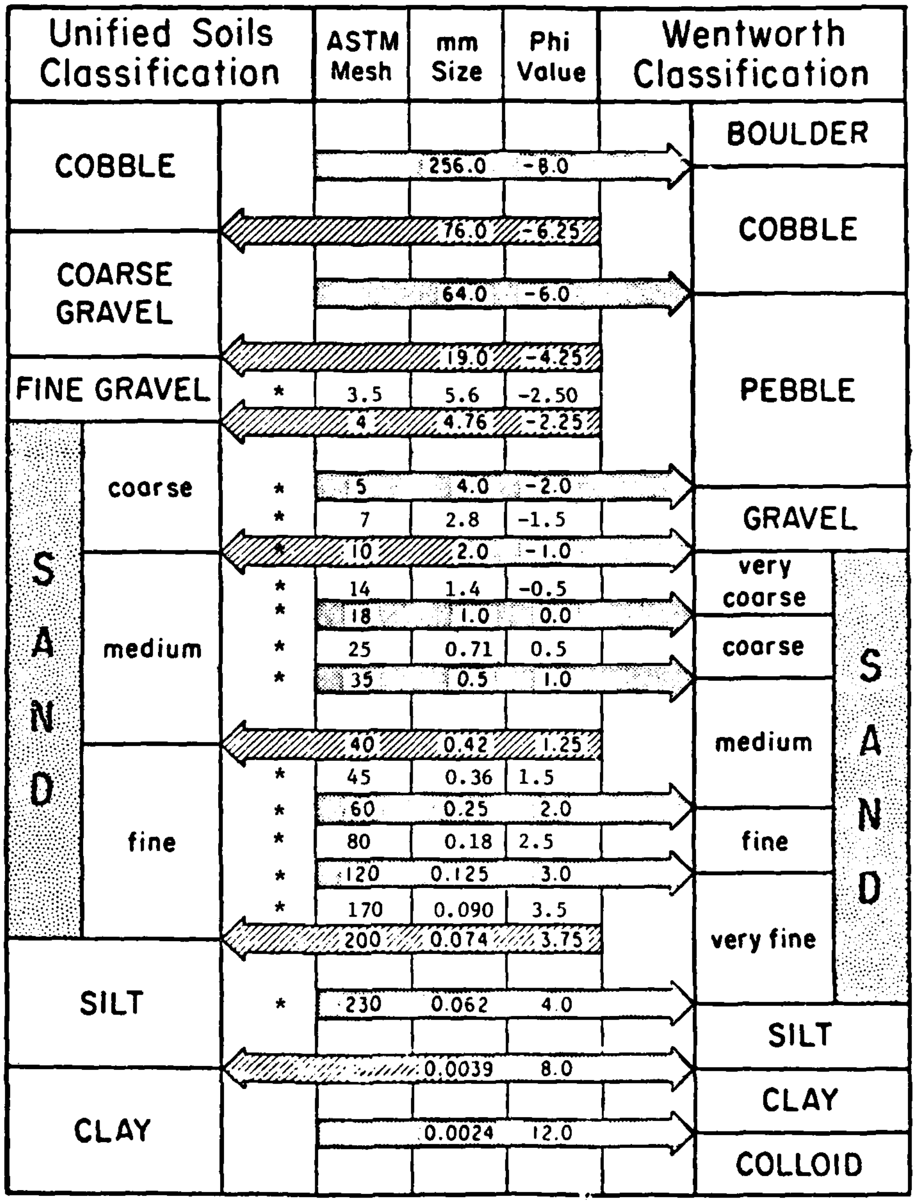
Figure 4. An example of measuring shear resistance (sand consistency) with a cone penetrometer

Penetration measurements adjacent to the turtle nests were taken from May to September in 1984 and 1985.

Grain size

15. A corer with a 5.1-cm outside diameter was used to take a 15.2-cm-deep sand sample at each station at the following depths: 0.0, 22.9, 53.3, and 83.8 cm.

16. Sand samples were tested according to standards established by US Army Engineer Manual 1110-2-1906 for soil testing (US Army Corps of Engineers 1970). Sieve sizes, particle diameters, and phi values are given in Figure 5.



* Sizes used for this study.

Figure 5. Grain size scales (soil classification) (adapted from Coastal Engineering Research Center 1984)

Sand shape

17. The following sieve sizes were grouped for shape analysis: 3.5, 5.0 and 7.0, 10.0 and 14.0, 18.0 and 25.0, 35.0 and 45.0, and 60.0 and 80.0 and 120.0. To determine the percentage of flat grains, 100 grains of sand were randomly selected from each group, and the number of flat versus round grains was counted (US Army Engineer Waterways Experiment Station 1983). A flat particle was defined as one with a ratio of width to thickness greater than three.

Moisture and density measurements

18. A 3411B Troxler Compac moisture density gage was used to measure density and moisture in 0.028 cu m of sand below a beach depth of 15.2 cm (read 15.2 to 45.7 cm), 45.7 cm (read 45.7 to 76.2 cm), and 76.2 cm (read 76.2 to 107.7 cm) (Figure 6).

In situ biological data

19. Sea turtle nests were marked and monitored in each of the three study areas to determine the effects of nourishment beach sand on the survival of the eggs and hatchlings (Figure 7). All nests in the two reference areas were marked immediately after the turtles had nested. Thirty-nine nests were left in situ in the nourished area, and all other nests were relocated to a fenced hatchery on the beach.

20. In situ nests were excavated (Figures 8 and 9) after an appropriate incubation period, and the following data were recorded:

- a. Location of nest by transect.
- b. Distance of nest from the wrack line.
- c. Distance of nest to the base of the dune or to the start of vegetation.
- d. Shear resistance adjacent to nest.
- e. Nest depth.
- f. Incubation period (date laid to the date when hatchlings emerged).
- g. Total number of eggs (in situ determined by adding the numbers of empty shells, unhatched eggs, and piped dead hatchlings in the shell) (Figure 10.).
- h. Number of unhatched eggs.
- i. Number of piped dead hatchlings in the eggshell.
- j. Number of dead hatchlings (completely free of the eggshell) in the nest.

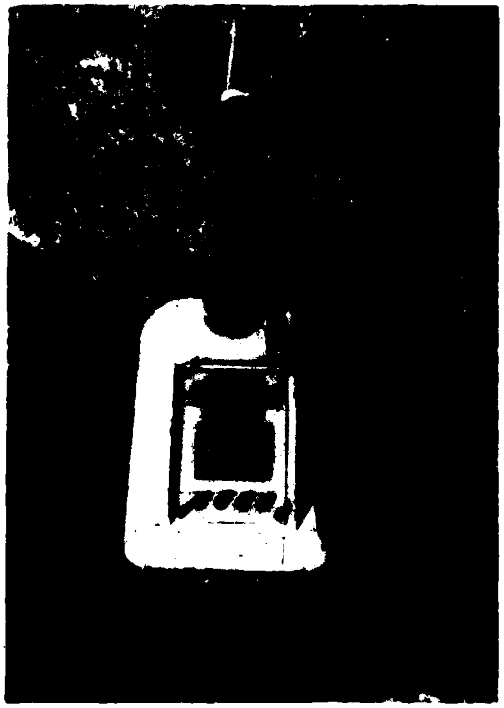


Figure 6. Example of taking measurements with moisture density gage

k. Number of live hatchlings in the nest.

21. False crawls (Figure 11) were drawn on data sheets, and the following information was recorded for them:

a. Date.

b. Location by transect.

c. Distance of the apex of the crawl from the wrack line.

d. Distance of the apex of the crawl from the base of the dune or edge of the vegetation.

These data were also recorded for false digs (Figure 12).

Hatchery biological data

22. Three equal-size areas (203.2 by 228.6 cm) within a fenced hatchery were separated, and one area was filled with aragonite sand, one with sand from the nourished beach, and one with natural beach sand (Figure 13). Clutches were removed from the nourished beach and placed into the three sand types sequentially until the areas were filled (26 clutches per area). The

Figure 7. An example of a marked nest in the renourished beach

cavities into which these clutches were placed simulated natural nest cavities; they were 45.7 to 50.8 cm deep and were spaced approximately 15.2 cm apart. The clutches were marked with stakes and monitored until hatchlings emerged from the nest. The same data as those specified previously for in situ nests were recorded for hatchery nests. The total number of eggs was determined by counting the eggs when they were relocated.

Data analysis

23. Data were recorded on standard data sheets, entered into a computer, and analyzed using the Statistical Analysis System (SAS Institute 1985). The Student's t-test, analysis of variance techniques, and Duncan's multiple range tests were used in the data analysis to determine differences in sampled parameters before and after nourishment and between the project area and the reference areas.

Results of Physical Data

24. The physical properties of the beach were compared using Duncan's multiple range tests ($P \leq 0.05$) and One-Way ANOVA ($P \leq 0.05$) between each of

a. Loggerhead turtle crawl with nest, Delray Beach, Florida

b. Loggerhead turtle crawl with nest, St. Lucie, Florida

Figure 8. Typical crawls with nests of loggerhead turtles

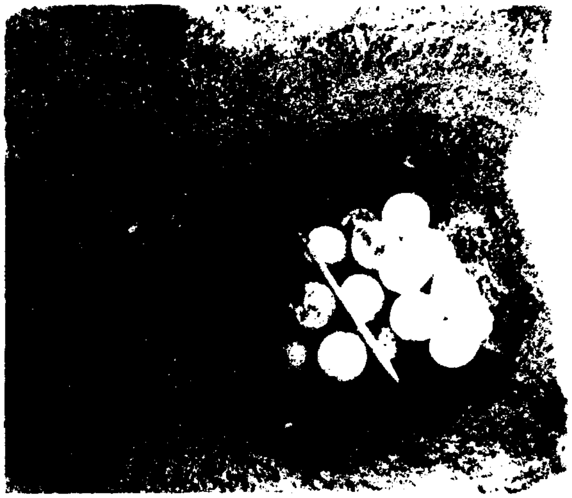


Figure 9. Exposed clutch of deposited loggerhead turtle eggs (pencil included as an indication of size)

Figure 10. Hatching success being determined for an in situ loggerhead nest in Delray Beach, Florida

a. Looking inward to land

b. Looking outward to sea

Figure 11. Typical false crawls of loggerhead turtles

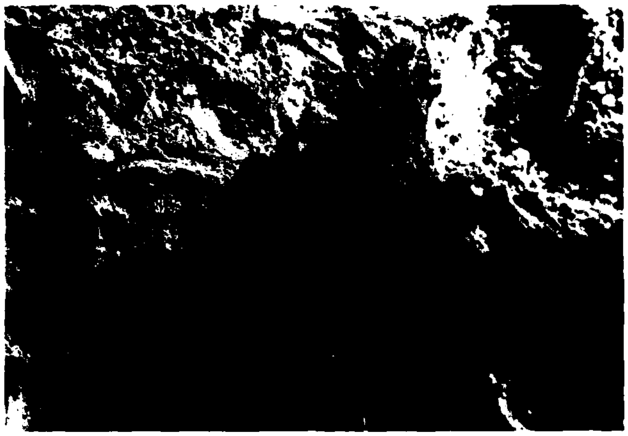


Figure 12. An example of a false dig (approximately 15 cm deep) in the renourished beach

Figure 13. Hatchery with marked nests in argonite sand (foreground), nourished sand (middle), and natural sand (background)

the following groups: (a) postnourishment project area (postproject), (b) prenourishment project area (preproject), (c) postnourishment north reference area (postnorth), (d) prenourishment north reference area (prenorth), (e) postnourishment south reference area (postsouth), and (f) prenourishment south reference area (presouth). Data for transects, stations, and depths were combined for each group for these comparisons.

Beach sand shear resistance

25. Postnourishment shear resistance was significantly higher in the project area than prenourishment shear resistance in the project area and prenourishment and postnourishment shear resistance in both reference areas (Table 2). Prenourishment shear resistance was significantly higher in the project area than prenourishment and postnourishment in both reference areas. Shear resistance was not significantly different in the reference areas from prenourishment to postnourishment; however, prenourishment shear resistances in the reference areas were significantly different from each other.

Compaction

26. The percentage of compaction was significantly higher postnourishment in the project area than it had been in the project area prenourishment and in the two reference areas prenourishment and postnourishment (Table 2).

Dry density

27. Postnourishment dry density for both reference areas was higher than the prenourishment dry density for the project area. Postnourishment dry density for the south reference area was significantly higher than postnourishment dry density for the project area (Table 2).

Moisture content

28. No significant differences were found in the percentages of moisture content among the three areas during prenourishment or postnourishment (Table 2).

Grain size

29. The 1.0-mm (0.0-phi), 0.71-mm (0.5-phi), and 0.50-mm (1.0-phi) grain sizes for presouth sand had significantly higher percentages by weight than all other groups (Tables 3 and 4). The 0.50-mm (1.0-phi) grain size for preproject sand was significantly lower in percentage by weight than the postsouth and presouth sands. The 0.50-mm (1.0-phi) grain size for postproject sand was significantly lower in percentage by weight than the sand in all the other groups.

Table 2

Comparison of Physical Properties of Sand for Project and Reference Sands Using Duncan's Multiple Range Tests and One-Way ANOVA (P = 0.05), Delray Beach, Florida*

Physical Properties	Duncan's Multiple Range Tests**						ANOVA (185 DF)	
							F	P
Shear resistance† (cone index)	Post-P 556.3	Pre-P 356.8	Pre-S 252.5	Post-S 166.9	Pre-N 143.9	Post-N 113.3	33.17	0.0001
Compaction† (%)	Post-P 97.2	Post-S 93.3	Post-N 92.2	Pre-N 91.3	Pre-P 91.0	Pre-N 90.8	10.55	0.0001
Dry density†† (lb/cu ft)	Post-S 104.0	Post-N 103.0	Pre-S 101.9	Pre-N 101.3	Post-P 100.8	Pre-P 100.0	2.55	0.03
Moisture†† (%)	Post-S 9.3	Pre-S 9.1	Pre-P 8.8	Post-P 8.7	Pre-N 8.1	Post-N 7.3	0.39	0.86

* Numbers connected by underlining are not statistically different (P = 0.05)

** Pre = prenourishment, Post = postnourishment, N = north reference, P = project, S = south reference.

† Measurements at all depths were combined.

†† n = 18 Pre-N, n = 17 Post-N, n = 36 Pre-P, n = 36 Post-P, n = 18 Pre-S, n = 18 Post-S.

Table 3

Comparison of Grain Sizes by Mean Percentage by Weight Using Duncan's Multiple Range Tests and One-Way ANOVA (P = 0.05), Delray Beach, Florida*

Phi Grain Size	Mean Percentage by Weight**						One-Way ANOVA (185 DF) F	P
-2.50	Post-P	Pre-S	Pre-N	Post-S	Post-N	Pre-P		
	0.69	0.43	0.37	0.33	0.14	0.06	1.73	0.13
-2.00	Pre-S	Post-P	Post-S	Pre-N	Pre-P	Post-N	1.10	0.36
	0.42	0.25	0.16	0.15	0.13	0.10		
-1.50	Post-P	Pre-S	Pre-N	Pre-P	Post-S	Post-N	1.32	0.26
	0.41	0.40	0.34	0.13	0.12	0.12		
-1.00	Post-P	Pre-S	Pre-N	Pre-P	Post-S	Post-N	1.37	0.24
	0.55	0.45	0.41	0.21	0.20	0.18		
-0.50	Post-P	Pre-S	Pre-N	Pre-P	Post-S	Post-N	1.21	0.30
	0.85	0.85	0.75	0.49	0.36	0.32		
0.00	Pre-S	Post-P	Pre-N	Pre-P	Post-S	Post-N	2.02	0.08
	2.10	1.17	1.08	1.01	0.85	0.85		
0.50	Pre-S	Post-S	Pre-P	Post-N	Pre-N	Post-P	5.09	0.0002
	4.71	3.11	2.28	2.24	2.17	2.01		

(Continued)

* Numbers connected by underlining are not statistically different (P=0.05).

** pre = predisposal, Post = postdisposal, N = north reference, P = project, S = south reference, n = 24 Pre-N, n = 23 Post-N, n = 48 Pre-P, n = 48 Post-P, n = 24 Pre-S, n= 24 Post-S.

Table 3 (Concluded)

Phi Grain Size	Mean Percentage by Weight**						One-Way ANOVA (185 DF) F	P
1.0Ø	Pre-S	Post-S	Pre-N	Post-N	Pre-P	Post-P	19.39	0.0001
	18.55	14.33	11.64	11.63	10.20	4.58		
1.5Ø	Pre-N	Post-S	Pre-S	Post-N	Pre-P	Post-P	39.04	0.0001
	34.47	31.76	31.50	31.29	26.37	9.98		
2.0Ø	Post-N	Pre-N	Post-S	Pre-P	Pre-S	Post-P	24.42	0.0001
	40.47	38.49	33.70	32.74	27.94	18.63		
2.50	Post-P	Pre-P	Post-S	Pre-S	Post-N	Pre-N	21.56	0.0001
	23.75	15.40	12.33	10.47	9.73	8.57		
3.00	Post-P	Pre-P	Post-S	Pre-S	Post-N	Pre-N	60.14	0.0001
	29.49	8.17	1.49	1.36	0.54	0.52		
3.50	Post-P	Pre-P	Pre-S	Post-N	Pre-N	Post-S	31.77	0.0001
	5.60	1.32	0.03	0.02	0.00	0.00		
4.00	Post-P	Pre-P	Pre-N	Pre-S	Post-N	Post-S	17.13	0.0001
	0.30	0.06	0.00	0.00	0.00	0.00		
>4.00	Post-P	Pre-N	Pre-P	Post-S	Pre-S	Post-N	3.31	0.007
	2.25	1.34	1.31	1.25	0.95	0.84		

30. The 0.36-mm (1.5-phi) grain size for preproject sand was significantly lower in percentage by weight than in presouth, postsouth, prenorth, and postnorth sand. The 0.36-mm (1.5-phi) grain size for postproject sand was significantly lower in percentage by weight than preproject, presouth, postsouth, prenorth, and postnorth.

31. The 0.25-mm (2.0-phi) grain size for postproject sand was significantly lower in percentage by weight than in all other groups. The 0.25-mm (2.0-phi) grain size for presouth sand was significantly lower in percentage

Table 4

Average Grain Size Distribution by Percent Weight and Cumulative Percentages for Delray Beach, Florida

Grain Size		Prenorth* (n = 24)		Postnorth (n = 23)		Preproject (n = 48)		Postproject (n = 48)		Presouth (n = 24)		Postsouth (n = 24)	
Sieve	(Phi)	% Wt	Cum %	% Wt	Cum %	% Wt	Cum %	% Wt	Cum %	% Wt	Cum %	% Wt	Cum %
3.5	(-2.5)	0.37	0.37	0.14	0.14	0.06	0.06	0.69	0.69	0.43	0.43	0.33	0.33
5.0	(-2.0)	0.15	0.52	0.10	0.24	0.13	0.19	0.25	0.94	0.42	0.85	0.16	0.49
7.0	(-1.5)	0.34	0.86	0.12	0.36	0.13	0.32	0.41	1.35	0.40	1.25	0.12	0.61
10.0	(-1.0)	0.41	1.27	0.18	0.54	0.21	0.53	0.55	1.90	0.45	1.70	0.20	0.81
14.0	(-0.5)	0.75	2.02	0.32	0.86	0.49	1.02	0.85	2.75	0.85	2.55	0.36	1.17
18.0	(0.0)	1.08	3.10	0.85	1.71	1.01	2.03	1.17	3.92	2.10	4.65	0.85	2.02
25.0	(0.5)	2.17	5.27	2.24	3.95	2.28	4.31	2.01	5.93	4.71	9.36	3.11	5.13
35.0	(1.0)	11.64	16.91	11.63	15.58	10.20	14.51	4.58	10.51	18.55	27.91	14.33	19.46
45.0	(1.5)	34.47	51.38	31.29	46.87	26.37	40.88	9.98	20.49	31.50	59.41	31.76	51.22
60.0	(2.0)	38.49	89.87	40.47	87.34	32.74	73.62	18.63	39.12	27.94	87.35	33.70	84.92
80.0	(2.5)	8.57	98.44	9.73	97.07	15.40	89.02	23.75	62.87	10.47	97.82	12.33	97.25
120.0	(3.0)	0.54	98.98	0.52	97.59	8.17	97.19	29.49	92.36	1.36	99.18	1.49	98.74
170.0	(3.5)	0.00	98.98	0.02	97.61	1.32	98.51	5.60	97.96	0.03	99.21	0.00	98.74
230.0	(4.0)	0.00	98.98	0.00	97.61	0.06	98.57	0.30	98.26	0.00	99.21	0.00	98.74
>230.0	(>4.0)	1.34	100.32	0.84	98.45	1.31	99.88	2.25	100.51	0.95	100.16	1.25	99.99

* Pre = prenourishment, Post = postnourishment.

by weight than in postsouth, prenorth, and postnorth sands. The 0.25-mm (2.0-phi) grain size for preproject sand was significantly lower in percentage by weight than in postnorth sand.

32. The 0.18-mm (2.5-phi), 0.125-mm (3.0-phi), 0.090-mm (3.5-phi), and <0.062-mm (>4.0-phi) grain sizes for postproject sand were significantly higher in percentage by weight than in sand of all other groups. The 0.18-mm (2.5-phi) grain size for preproject and postsouth sands was not significantly different; however, both these sands were significantly higher in percentage by weight than in presouth, prenorth, and postnorth sands. The 0.125-mm (3.0-phi) grain size for preproject sand was significantly higher in percentage by weight than in presouth, postsouth, prenorth, and postnorth sands.

33. The phi median diameter was larger (smaller diameter, see Figure 5) for postproject sands (2.23 phi) than for preproject (1.64 phi), prenorth (1.48 phi), postnorth (1.54 phi), presouth (1.36 phi), and postsouth sands (1.48 phi) (Table 5).

34. The phi mean diameter was larger (smaller diameter, see Figure 5) for postproject sand (2.08 phi) than for preproject (1.69 phi), prenorth (1.44 phi), presouth (1.32 phi), and postsouth sands (1.44 phi) (Table 5).

35. The phi sorting was larger (more poorly sorted, well graded) for postproject sand (0.79) than for preproject (0.66), prenorth (0.48), postnorth (0.47), presouth (0.63), and postsouth sands (0.55) (Table 5).

36. The percentage of sand in the six groups ranged from 97.6 to 99.2 percent (Table 5).

Sand grain shape analysis

37. Sand grain shapes range from 1 to 6, with shape 1 being the coarsest and shape 6 being the finest (US Army Engineer Waterways Experiment Station 1983). In the six sample groups, shapes 1 and 2 were not significantly different in the percentage of flat grains (Table 6).

38. Shape 3 postproject sand had a significantly lower percentage of flat grains than did postsouth reference sand.

39. Shape 4 for postsouth and presouth sands were not significantly different from each other in percentage of flat grains; however, they both had a significantly higher percentage of flat grains than did preproject, postproject, prenorth, and postnorth sands.

40. Shapes 5 and 6 were significantly higher in percentage of flat grains in postproject sand than in all other sample groups. Shape 5 presouth

Table 5

Comparison of Average Grain Size Distribution Parameters for Project and Reference Areas at Delray, Florida

Textural Properties	Prenorth* (n = 24)	Postnorth (n = 23)	Preproject (n = 48)	Postproject (n = 48)	Presouth (n = 24)	Postsouth (n = 24)
16 phi	0.96	1.01	1.03	1.29	0.69	0.88
50 phi (Phi median diam)	1.48	1.54	1.64	2.23	1.36	1.48
84 phi	1.92	1.96	2.34	2.86	1.95	1.99
σ phi (84-16 phi)/2 (Phi sorting)	0.48	0.47	0.66	0.79	0.63	0.55
M phi (84 + 16 phi)/2 (Phi mean diam)	1.44	1.49	1.69	2.08	1.32	1.44
Sand, %	99.0	97.6	98.5	98.0	99.2	98.7

* Pre = prenourishment, Post = postnourishment.

and postsouth sands were significantly higher in percentage of flat grains than were preproject, prenorth, and postnorth sands. Shape 5 preproject sand was significantly higher in percentage of flat grains than were prenorth and postnorth sands. Shape 6 postsouth sand was significantly higher in percentage of flat grains than were preproject, presouth, postnorth, and prenorth sands.

Scarp formation

41. A scarp formed in both the nourished beach and the reference beaches following renourishment and subsequent winter storms. Approximately 25 percent of the renourished beach had a scarp that ranged from a few centimetres to 1.5 m in height (Figure 14).

Table 6

Comparison of Mean Percentage of Flat Grains for Reference and Project Sands Using Duncan's Multiple Range Tests and One-Way ANOVA (P ≥ 05), Delray Beach, Florida

Grain Size Range*	Mean Percentage by Number**						One-Way ANOVA (185 DF) F	P
1	Post-S† 45.8	Post-N 34.0	Pre-N 32.4	Post-P 32.0	Pre-S 21.5	Pre-P 15.8	2.04	0.07
2	Post-S 70.8	Pre-S 65.5	Post-P 63.0	Pre-P 56.3	Post-N 50.2	Pre-N 49.8	0.94	0.45
3	Post-S 95.4	Pre-N 88.8	Post-N 86.4	Pre-S 85.0	Pre-P 80.7	Post-P 71.3	5.13	0.0002
4	Post-S 58.9	Pre-S 54.9	Pre-N 44.4	Post-P 42.4	Pre-P 42.2	Post-N 37.6	12.37	0.0001
5	Post-P 25.2	Post-S 21.8	Pre-S 19.2	Pre-P 16.2	Pre-N 13.1	Post-N 12.1	29.28	0.0001
6	Post-P 16.0	Post-S 13.0	Pre-P 9.3	Pre-S 9.0	Post-N 7.7	Pre-N 7.4	23.04	0.0001

* The number of flat grains per 100 grains were counted from each of the following groups of grain sizes:

Size Range	Sieve Sizes Passing	Retained
1	-	3.5 (5.60 mm, -2.5Ø)
2	3.5	7.0 (2.80 mm, -1.5Ø)
3	7.0	14.0 (1.40 mm, -0.5Ø)
4	14.0	25.0 (0.71 mm, 0.5Ø)
5	25.0	45.0 (0.355 mm, 1.5Ø)
6	45.0	120.0 (0.125 mm, 3.0Ø)

** Numbers connected by underlining are not statistically different (P = 0.05).

† Pre = predisposal, Post = postdisposal, N = north reference, P = project, S = south reference.

Figure 14. Example of scarp formation after beach renourishment, Delray Beach, Florida, January 1985

Results of Biological Data

Hatchery nests in aragonite, renourished, and natural sand

42. The hatchery nests were incubated in aragonite, renourished, and natural sands. The incubation period was significantly shorter in natural (mean, 52.5 days) than in aragonite sand (mean, 54.0 days) (Table 7). No significant difference was found in the three sand types for the total number of eggs, number of eggs hatched, number of live hatchlings, and percentage of hatch (number of eggs hatched divided by the total number of eggs times 100) (Table 7). Clutches in the sand from the renourished beach had significantly fewer unhatched eggs (mean, 14.0) than did clutches in the natural sand (mean,

Table 7

Hatchery Data for Nests in Aragonite (A), Renourished (R), and Natural (N) Sand, Duncan's Multiple Range test and One-Way ANOVA ($P \geq 0.05$, $n = 26$)*

Hatchery Data	Duncan's Multiple Range Test			ANOVA		
				F	P	DF
Incubation period	A 54.0	R 53.2	N 52.5	3.21	0.05	75
Number of eggs	A 117.3	N 110.1	R 108.0	1.48	0.23	76
Number of eggs hatched	R 92.3	A 90.7	N 82.5	0.96	0.39	76
Number unhatched eggs	N 26.1	A 23.0	R 14.0	2.42	0.10	76
Number of piped dead hatchlings	A 3.5	R 0.8	N 0.5	4.23	0.02	76
Number of Dead hatchlings	N 1.5	A 0.4	R 0.3	3.56	0.03	76
Percentage of Hatch no. eggs hatched/no. eggs	R 86.1	A 76.8	N 75.2	2.47	0.09	76
Number of live hatchlings	R 92.8	A 90.4	N 81.0	1.39	0.26	76

* Means connected by underlining are not significantly different.

26.1) (Table 7). Clutches in the aragonite sand had a greater number of piped dead hatchlings (mean, 3.5) than did clutches in nourishment sand (mean, 0.8) and natural sand (mean, 0.5). Clutches in natural sand had a significantly larger number of dead hatchlings (mean, 1.5) than did clutches in aragonite sand (mean, 0.4) and nourishment sand (mean, 0.3).

Number of nests and false crawls

43. In the project area from 1984 (prenourishment) to 1985 (postnourishment), the number of nests decreased by 27 percent, the number of false crawls increased by 13 percent, the number of emergences decreased by 4 percent, the number of nests per false crawl decreased by 41 percent, and the number of nests per emergence decreased by 24 percent (Table 8).

Table 8

Comparison of the Number of Nests, False Crawls, and Emergences for Loggerhead Turtles, 1984 and 1985, Delray Beach, Florida

Number per 2,000 ft	1984			1985		
	North	Project	South	North	Project	South
False crawl with dig				4.7	3.0	6.1
Total digs				5.4	3.7	8.0
False crawl without dig				43.3	28.6	36.2
Total false crawls	32.4*	25.4	29.4*	48.0	31.6	42.3
Nests	40.7*	31.1	48.9*	48.2	22.7	55.8
Total emergences	73.1*	56.6	78.3*	96.0	54.4	96.2
Nests per false crawl	1.11	1.22	1.47	1.00	0.72	1.32
Nests per emergence	0.53	0.55	0.59	0.50	0.42	0.58
Nests per excavation**				0.89	0.85	0.87
Digs per excavation**				0.11	0.15	0.13

* Data for the north and south reference areas were taken only from 15 June to 30 September 1984; therefore, the data were interpolated from project area data taken for 1 May to 30 September 1984.

** An excavation is any cavity dug by the turtle including each nest and each false dig hole.

44. A census of nesting data in the two reference areas was not initiated until mid-June 1984; therefore, the number of false crawls, nests, and emergences was interpolated. Based on this interpolation, it appears that in the reference areas from 1984 to 1985, the number of nests increased (18 percent in the north, 14 percent in the south), the number of false crawls increased (34 percent in the north, 23 percent in the south), the number of

emergences increased (31 percent in the north, 23 percent in the south), the number of nests per false crawl decreased (10 percent in the north, 10 percent in the south), and the number of nests per emergence decreased (6 percent in the north, 2 percent in the south).

Nest parameters

45. Since prenourishment in 1984, clutches laid in the project area were relocated and incubated in a hatchery; the number of eggs, number of eggs hatched, number of eggs unhatched, number of piped dead hatchlings, number of dead hatchlings, number of live hatchlings, and incubation period in a hatchery were not comparable with these same parameters for in situ nests. In addition, nests that had been preyed upon by foxes or inundated by seawater were excluded from the analysis because their inclusion would bias the potential differences resulting from nourishment. Data from all nests were used to determine the mean number of eggs per nest.

46. In the project, north, and south areas, the number of eggs per nest was not significantly different from each other in 1984 or in 1985. However, the number of eggs per nest in these areas in 1985 was significantly lower than the number of eggs per nest in the north area in 1984 (Table 9 and Appendix A).

47. The number of hatched eggs and unhatched eggs and the ratio of hatched eggs to number of eggs (hatch success) per nest were not significantly different between nests in the north in 1984, south in 1984, north in 1985, and south in 1985 (Table 9 and Appendix A).

48. The number of hatched eggs per nest for the project area in 1985 was not significantly different from the two reference areas in 1985. The number of hatched eggs per nest in the project area in 1985 was significantly lower than the number of hatched eggs per nest in the two reference areas in 1984 (Table 9 and Appendix A).

49. The number of unhatched eggs per nest was not significantly different between nests in the project in 1985 and in the two reference areas in 1985. However, the number of eggs hatched per nest was significantly higher in the project in 1985 than in the two reference areas in 1984 (Table 9).

50. The ratio of eggs hatched per nest to total number of eggs per nest (hatch success) was not significantly different between nests in the project area in 1985 and nests in the two reference areas in 1985 and in the

Table 9

Comparison of Data for In Situ Loggerhead Turtle Nests 1984 and 1985, Delray Beach, Florida, Using Duncan's Multiple Range Test and One-Way ANOVA (P ≥ 0.5)

Duncan's Multiple Range Test*							ANOVA F	ANOVA P	ANOVA DF
Distance of nest to wrack line (ft)									
S84	N84	P84	S85	N85	P85				
41.7	37.6	34.8	34.5	30.7	28.5		6.96	0.0001	876
Distance of nest to base of dune (ft)									
P85	P84	N85	N84	S84	S85				
113.3	50.8	46.2	35.8	35.5	34.9		139.34	0.0001	870
Ratio: distance of nest to wrack line relative to beach width									
S84	N84	S85	P84	N85	P85				
0.56	0.54	0.51	0.44	0.41	0.22		31.26	0.0001	870
Shear resistance adjacent to nests at the 6-in. depth (lb/sq in.)									
P85r	P85n	S85	S84	P84	N85	N84			
274.0	178.1	167.1	96.6	91.0	87.0	60.2	79.70	0.0001	602
Shear resistance adjacent to nests at the 12-in. depth (lb/sq in.)									
P85r	P85n	S85	P84	S84	N85	N84			
495.1	299.2	295.1	241.0	227.2	141.6	126.4	63.79	0.0001	602

(Continued)

* S = south reference area, N = north reference area; P = project area, r = renourished sand, and n = reworked, natural sand. Numbers connected by underlining are not significantly different.

Table 9 (Continued)

Duncan's Multiple Range Test*							ANOVA F	ANOVA P	ANOVA DF
Shear resistance adjacent to nests at the 18-in. depth (lb/sq in.)									
P85r	S85	P85n	P84	S84	N84	N85			
714.3	465.8	453.5	394.2	359.5	232.5	213.9	70.71	0.0001	598
Distance from the beach surface to the bottom of the nest (in.)									
N85	P84	S85	P85	N84	S84				
20.3	20.1	19.9	19.8	19.6	19.2		3.46	0.033	505
Incubation period (date eggs laid to date hatchlings emerge, days)**									
N85	N84	S84	P85	S85					
54.0	53.7	53.5	52.9	52.6			3.00	0.011	465
Number of eggs per nest									
N84	S84	P84	N85	P85	S85				
118.4	116.6	113.5	110.7	110.1	109.1		2.84	0.015	575
Number of eggs hatched per nest** †									
S84	N84	N85	S85	P85					
106.1	105.8	97.9	95.9	91.9			7.61	0.0001	489
Number of eggs unhatched per nest** †									
P85	S85	N85	N84	S84					
17.1	12.1	11.2	9.8	9.4			4.99	0.0002	488

(Continued)

* S = south reference area, N = north reference area, P = project area, r = renourished sand, and n = reworked, natural sand. Numbers connected by underlining are not significantly different.

** Project area nests in 1984 were all relocated to a hatchery and were excluded from the analysis.

† Nests that were inundated with seawater or predated upon by foxes were excluded from this analysis.

Table 9 (Concluded)

Duncan's Multiple Range Test*					ANOVA F	ANOVA P	ANOVA DF
Ratio: number of eggs hatched per nest to number of eggs per nest (hatch success)** †							
S84	N84	N85	S85	P85			
0.91	0.90	0.89	0.87	0.84	12.57	0.0001	488
Number of piped dead hatchlings per nest** †							
S85	N85	S84	N84	P85			
1.7	0.9	0.7	0.6	0.3	9.81	0.0001	487
Number of dead hatchlings per nest** †							
S84	P85	S85	N84	N85			
1.5	1.3	0.7	0.5	0.4	1.2	0.31	487
Number of live hatchlings per nest** †							
N84	S84	N85	S85	P85			
106.8	105.4	97.5	95.2	90.6	9.31	0.0001	487
Ratio: number of live hatchlings to number of eggs per nest (hatchling ratio)** †							
N84	S84	N85	S85	P85			
0.90	0.90	0.89	0.86	0.83	12.31	0.0001	487

* S = south reference area, N = north reference area, P = project area, r = renourished sand, and n = reworked, natural sand. Numbers connected by underlining are not significantly different.

** Project area nests in 1984 were all relocated to a hatchery and were excluded from the analysis.

† Nests that were inundated with seawater or predated upon by foxes were excluded from this analysis.

north in 1984. The hatch success for nests in the project area in 1985 was significantly lower than for nests in the south in 1984 (Table 9).

51. The number of piped dead hatchlings and the number of dead hatchlings in the nest were not significantly different for both years for the three areas (Table 9 and Appendix A).

52. The number of live hatchlings (including live hatchlings found in the nest) was not significantly different for nests in the three areas in 1985. The number of hatchlings per nest was significantly lower for the project area in 1985 than for nests in the two reference areas in 1984. The number of hatchlings per nest in the south reference area for 1985 was significantly lower than for nests in the north reference area in 1984. The number of hatchlings per nest in the north in 1984, the north in 1985, and the south in 1984 was not significantly different (Table 9).

53. The ratio of the number of live hatchlings to the number of eggs per nest (hatchling ratio) was not significantly different between the project area in 1985, south in 1984, south in 1985, and north in 1985, but the hatchling ratio for the project area in 1985 was significantly lower than the hatchling ratio for the north in 1984 (Table 9 and Appendix A).

Shear resistance adjacent to nests

54. Since a portion of the nourished beach had been reworked by winter storms after the nourishment, the measurements in the reworked sand in the project were separated for analysis (Table 9 and Appendix A).

55. As in the beach measurements, shear resistance increased with depth. At the 6-in. (15.2-cm) depth, shear resistances for nests in the project prenourishment were not significantly different from those in the two reference areas. Prenourishment shear resistances adjacent to nests at the 12- and 18-in. (30.4 and 45.6-cm) depths in the project and south reference area were not significantly different from each other; however, both were significantly higher than shear resistances in the north reference area for the two depths.

56. Postnourishment shear resistances at the 6-, 12-, and 18-in. depths adjacent to the nests in project sands were significantly higher than in reworked project, south reference, and north reference sands. Postnourishment shear resistances at all three depths adjacent to nests in the reworked project and south reference sands were not significantly different from each other, but both were significantly higher than north control area sands.

Nest location

57. Nests in the nourishment area both prenourishment and postnourishment were significantly closer to the wrack line than were nests in the south reference area, but they were not significantly different from nests in the north reference area (Table 9 and Appendix A).

58. Prenourishment and postnourishment project area nests were significantly farther from the base of the dune than were nests in the north and south reference areas. Nests in the nourishment area were significantly farther from the base of the dunes during postnourishment than during prenourishment. Nests in the two reference areas were not significantly different in relation to distance from the base of the dunes during prenourishment than during postnourishment.

Nest depth

59. The depth from the beach surface to the bottom of the nest (nest depth) in the north area was significantly shallower in 1984 than in 1985. Depths of nests were significantly shallower in the south area in 1984 than in the north area in 1985 and in the project area in 1984 (Table 9 and Appendix A).

False digs

60. The number of emergences (crawls onto the beach) with at least one false dig cavity (range one to three cavities per emergence) per 2,000 ft in 1985 was 3.0 for the project area, 4.7 for the north reference area, and 6.1 for the south reference area (Table 8). (False dig data were not recorded for 1984.) The number of digs per excavation (an excavation being a nest or dig cavity) for 1985 was 0.15 for the project area, 0.11 for the north reference area, and 0.13 for the south reference area. The mean depth of false digs was not significantly different for the project and two reference areas (Table 10).

61. The distances of the dig cavity both to the wrack line and to the base of the dune were significantly greater in the nourishment area than in the two reference areas. The ratio of distance of dig cavity to the wrack line to the width of the beach was not significantly different for the reference areas (Table 10).

62. The shear resistance in false digs was significantly higher in the nourishment area than in the two reference areas. The shear resistance in

Table 10

Comparison of False Dig Data for Loggerhead Turtles in 1985 Delray Beach, Florida, Using Duncan's Multiple Range Test, and One-Way ANOVA (P > 0.05)

Duncan's Multiple Range Test*			ANOVA F	ANOVA P	ANOVA DF
Depth of false dig cavity (in.)					
S85*	N85	P85			
13.3	11.4	10.4	1.05	0.357	72
Distance of false dig to wrack line (ft)					
P85	N85	S85	8.14	0.0007	74
64.6	29.8	29.3			
Distance of false dig to the base of the dune (ft)					
P85	N85	S85	11.81	0.0001	75
75.0	48.3	32.7			
Ratio: distance of false dig to wrack line to beach width					
S85	P85	N85	0.30	0.742	74
0.48	0.46	0.40			
Shear resistance in the false dig cavity (lb/ sq in.)					
P85	S85	N85	27.73	0.0001	85
737.1	479.5	255.4			

* S = south reference area, N = north reference area, and P = project area. Numbers connected by underlining are not significantly different.

false digs was also significantly higher in the south reference area than in the north reference area (Table 10).

Discussion of Physical Data

Beach sand shear resistance

63. The nourishment area sand increased in shear resistance (harder consistency) after nourishment, but sand in the reference area did not change in shear resistance after nourishment. This increase in shear resistance

following nourishment has been documented also for other beaches in Florida. Ehrhart and Raymond (1983) observed harder consistency following beach nourishment at Melbourne Beach, Florida, although quantitative measurements were not taken. A study by the US Army Engineer Waterways Experiment Station (WES) at St. Lucie Inlet, Florida (Nelson and Mayes 1986) also found a higher shear resistance for sand after beach nourishment. However, postnourishment shear resistance at St. Lucie Inlet (mean, 277.9) was much lower than postnourishment shear resistance for the present study (mean, 556.3).

64. For this study, the prenourishment shear resistance (mean, 356.8) was also significantly higher than for the two reference areas. This finding indicates that the nourishment area has maintained a hard consistency (though it has softened) since the previous nourishment in 1978, a period of 6 years.

Compaction

65. The nourishment sand increased in compaction after nourishment, whereas the reference areas remained unchanged. This increased compaction may be attributable to a shift to a finer, more poorly sorted grain size and/or to a more compacted sand fabric (structure). The weight of the sand-water slurry from the hydraulic pumping of the beach may have also contributed to the increased compaction.

Dry density

66. Although the project area appears to have a slightly lower mean dry density than the reference areas, the differences are small (0.8 to 3.9 percent) and are not significant.

Moisture

67. The means for the percentage of moisture ranged from 7.3 to 9.3 percent and were not significantly different. Moisture content of sand can affect hatching success in turtles (Gutzke 1984). The percentage of moisture was not affected by the beach nourishment. Also, this would preclude a determination that the differences in shear resistance and compaction between nourished and reference beaches are attributable to the differences in moisture content of the beaches.

Grain size

68. Some of the percentage by weight (approximately 36 percent) of the beach sediments shifted from medium and medium-fine grain sizes to fine, very fine, and silt grain sizes in the nourishment area after nourishment. The north reference area did not change in grain size from prenourishment to

postnourishment sampling; however, the south reference area had a small (approximately 5 percent) shift from medium to medium-fine grain size after nourishment. This change in finer sand may have resulted from littoral drift to the south. This could be observed by the presence of gray nourishment sand south of the nourishment area overlaying the yellow natural sand.

69. Sand in the nourishment area became slightly less sorted after nourishment (from 0.66 to 0.79). The median and mean sand diameter became finer, and the mean percentage of sand decreased slightly (approximately 0.5 percent decrease) in the nourishment area after nourishment. Phi sorting and mean and median sand diameter changed very slightly (>0.12) from prenourishment to postnourishment in the two reference areas. The change in mean and median grain size in the nourishment area is reflective of the shift in the percentage of medium and medium-fine grain sizes to finer sizes after nourishment.

Sand grain shape

70. Although some changes in the percentages of flat grains occurred after disposal, these changes do not appear to be of a magnitude that would affect consistency, particularly if the change in the percentage of flat grains is examined relative to the percentage by weight of a grain size. The percentages of flat grains may be more important when comparing the differences between two project areas rather than within project changes (e.g., St. Lucie data compared with Delray Beach data). While a project area may not show an increase in the percentage of flat grains, the flat grains may be reoriented by the hydraulic pumping to create a layered effect (Figure 15). This study did not include structural measurements to examine the possibility of layering (e.g., cross-sectioning of resined cores). However, evidence from this study suggests that layering may have occurred. Visual observation of scarps at Delray Beach after nourishment showed flat grains (shells) layering parallel to the beach surface (Figure 16). Additional evidence for layering may be found in a pilot study on the use of tilling to reduce the hard consistency of Delray Beach, Florida; this study indicated that the renourished sand can be softened by the tilling action (Nelson 1986). This softening of the sand by tilling could have resulted from the breaking up of the sand layered by the hydraulic fill.

Figure 15. An example of the sand water slurry being pumped onto a beach

Figure 16. Picture of beach scarp showing sand particle layering parallel to the beach surface

Scarp formation

71. Scarping may occur as a result of nourishment when there is an abrupt transition between steep fill slope and a flatter natural offshore slope. Steep scarps may develop at the toe of the fill as waves begin the readjustment into a more equilibrated profile shape (Coastal Engineering Research Center 1984). Scarp formation will vary with wave and current magnitude. At Delray Beach, scarps formed after renourishment following storms during the winter. These scarps were reduced in elevation, some by the spring turtle-nesting season. Most of the remaining scarp formation was tapered with beach raking equipment by the City of Delray Beach. Scarps also formed in the reference areas, particularly in the south, where some scarps up to 3 ft in height were observed (Figure 17).

Compaction caused by equipment operation

72. It is difficult to separate the amount of compaction caused by the nourishment process from that caused by the operation of heavy equipment on the beach. However, observation of tracks left by equipment used on the beach during nourishment (Figure 18) and of the impenetrability of the sand in these tracked areas indicates that compaction by the equipment does occur. Compaction occurs particularly with narrow-tracked vehicles and generally near the dune line where the equipment most often operates.

Discussion of Biological Data

Hatchery nests in aragonite, renourished, and natural sand

73. Clutches placed in aragonite sand had a mean incubation period that was 1.5 days longer than those in natural sand. Observations of temperatures in the three sand types suggest that clutches in the aragonite had slightly cooler temperatures than did the other sand types. These cooler temperatures, which may have been caused by greater reflectance of the white aragonite, may have contributed to the longer incubation periods.

74. Clutches in aragonite sand had a higher mean number of piped dead hatchlings than did clutches in renourished or natural sand in the hatchery. The mean number of piped dead hatchlings in the hatchery aragonite sand was also higher than for in situ nests. The reason for a higher number of piped dead hatchlings is unclear; however, a fine, white aragonite coating was

Figure 17. Scarp formation in south reference area Delray Beach, Florida. A turtle crawled up to the scarp and then returned to the water; on a following day, it crawled up and over the scarp and nested

observed on the piping hatchlings. This clay-like coating clung to the moisture on the hatchlings and may have interfered with their respiration.

75. No adverse effect of renourished sand on eggs or hatchlings was observed in the hatchery nests. This agrees with the results for in situ nests in this study and with a nourishment study conducted on Melbourne Beach, Florida, by Ehrhart and Raymond (1983).

76. Clutches in the natural sand had a higher mean number of hatchlings dead in the nest than did clutches in the other two sand types in the hatchery. The cause of the higher number of dead hatchlings is unknown; however, the number of dead hatchlings was within the range found for in situ nests.

Number of nests, false
crawls, and emergences

77. The number of emergences in the project area decreased slightly (2.2 percent) from 1984 to 1985, whereas the number of nests per emergence decreased substantially (13.0 percent) (Table 8). At the same time, the number of emergences in the reference areas appeared to increase substantially (in the north 23.0 percent, in the south 17.9 percent), whereas the number of nests per emergence decreased only slightly (in the north 3.0 percent, in the

a. Equipment used for beach nourishment, Delray Beach, Florida

b. Compacted roadway left by equipment, Delray Beach, Florida

Figure 18. Example of equipment and compaction caused by equipment operation on Delray Beach during renourishment

south 1.0 percent). These results indicate that the turtles were not digging nests as often in the nourished beach, even though they were emerging onto the beach. This might have been due to the turtles' response to physicochemical changes in the beach sand or to a biotic effect such as human disturbance of the turtle. Since the nourished beach is a public beach, it receives a great deal more pedestrian traffic than the reference beaches receive. Disturbance of turtles was probably higher on the nourished beach because nighttime activity was observed to be higher. However, human activity did not noticeably increase enough from 1984 to 1985 to account for the decrease in nest per emergence.

78. It seems likely that the turtles are responding to some physicochemical change in the beach resulting from the nourishment. Beach hardness, temperature, moisture, and elevation are some physical parameters to which turtles may be responding. Salinity and pH are possible chemical cues. The false dig results in this study suggest that beach hardness may be contributing to the rejection of a nest site, but hardness does not seem to contribute to the selection of a nest site. The data show no differences in moisture content; thus, turtles do not have a difference to detect. Stoneburner and Richardson (1981) have suggested that temperature may be a factor in nest site selection. Elevation may be implicated as a factor in nest site selection since turtles appeared to nest closer to the wrack line in the nourishment area, which was higher in elevation than were the reference areas.

Nest parameters

79. Because of two storms that inundated about 20 percent of the nests (Figure 19), predation on nests (Figure 20), and loss of nest markers to pedestrians, only 10 out of 39 nests marked in the project area in 1985 had data that could be used for comparison of differences in nesting parameters between the nourished beach and the two reference areas.

80. None of the nest parameters (number of eggs, number of eggs hatched, number of eggs unhatched, hatch success, number of piped dead hatchlings, number of dead hatchlings, number of live hatchlings, and hatchling ratio) were significantly different for the nourished beach, north beach, and south beach in 1985 and for the north beach and south beach in 1984. Some of the nest parameters of the nourished beach in 1985 were significantly different from the reference beaches in 1984; however, these comparisons are not meaningful in determining beach nourishment effects because the "natural"

Figure 19. Example of marked nests that had been inundated by water from storms at Delray Beach, Florida, in July 1985 (note the wrack line or debris relative to the stakes marking the nests)

Figure 20. A fox preying upon hatchlings from loggerhead nests, Delray Beach, Florida

annual variability in biological and physicochemical factors cannot be separated from the beach nourishment effects.

Shear resistance adjacent to nests

81. The change to a higher shear resistance (harder consistency) at the 6-, 12-, and 18-in. (15.2-, 30.4-, and 45.6-cm) depths for sand adjacent to nests in the project area than for sand adjacent to nests in the reference areas resulted from the nourished sand deposited on the nourishment area but not on the reference area. The higher shear resistance also shows that the difference existed approximately 7 to 11 months after disposal. These results also indicate that turtles will dig nests within a broad range of shear resistances (Table 9). The shear resistance increased with depth because of the pressure of the sand overburden. The weight of overlying sand affects the pressure on sand grains; thus, it affects the shear resistance.

82. The higher shear resistance for the south reference area after nourishment suggests that this area may have been affected by the nourishment. The apparent movement of the gray nourished sand southward is indicated by the shift from yellow to gray sand. Also, the grain size analysis showed an increase of finer sand in the south reference area postnourishment that did not occur in the north reference area. The reworked sand seaward of the nourished beach showed shear resistances that were similar to those in the south reference area in 1985, suggesting that this sand is still influenced by the nourished sand, even though it has been reworked by waves and storms. (One could hypothesize that the reworked sand would show the presence of fine sand similar to the south reference area.)

Nest location

83. Even though the width of the beach was increased an average of 60 ft from prenourishment to postnourishment, the turtles seemed to nest in closer proximity to the wrack line than to the dune line in the project area. On the average, nests were not spaced out over the wider expanse of project beach after nourishment but were clustered nearer the wrack line than to the dunes.

Nest depth

84. Even though shear resistance increased in the nourishment and south areas from 1984 to 1985, the nest depths were not significantly different from one year to the next. The nest depths ranged from 15 to 26 in. (38.1 to 66.0 cm) deep for the three areas in 1984 and 1985. The WES investigators

expected to find shallower nests in sands with harder consistency, but the results showed no significant difference for areas between prenourishment and postnourishment nests. Ehrhart and Raymond (1983) reported that nest cavities dug in hard sand were too shallow and/or narrow, causing the eggs to "overflow" the cavity and to be broken by the turtle's flippers. Fletemeyer (1983b) reported that loggerhead nests were shallower in renourished beaches than in natural beaches. In the present study, shallow nests were found in both hard and soft sand; however, researchers did observe some nest cavities in the harder sand that did not exhibit the typical flask shape but instead were tapered at the bottom and were at angles to the beach surface instead of the general perpendicular orientation. This suggests that the "overflow" of eggs may have been a function of cavity size rather than of depth. The nest depth and false dig data suggest that turtles dig to within a narrow range of nest depths and, if this depth cannot be achieved, the turtle will abandon the site. This digging action of the turtle could be an innate characteristic related to hind flipper length or reach. As reported by Ehrhart and Raymond (1983), WES personnel observed a stump-legged turtle having trouble excavating a nest. This turtle dug two cavities before nesting in a third one in the north area.

False digs

85. This study also addressed the consistency or hardness of sand rejected by nesting turtles (as evidenced by false digs) and the number of sites rejected by the nesting turtles. This study did not address whether additional time and effort are required for turtles to dig in sand with a harder consistency. The number of rejected nest sites can be determined by counting the number of false digs. The sand consistency that is rejected can be determined by measuring shear resistance in the false digs. The additional time required to excavate a nest in sands of a harder consistency can be estimated by comparing digging times with shearing resistance adjacent to the nest.

86. While the number of false digs in the nourishment area appears to be less than in the two reference areas, the number of digs is relative to turtle activity on the beach (i.e., if the amount of turtle activity on a beach is low, then the number of digs will be proportionately low). To account for the dependency of false digs on the overall nesting activity, WES investigators analyzed the ratio of the number of false digs to the number of

total excavations (false digs plus nest cavities). This ratio showed slightly more false digs per excavation in the nourishment area than in the two reference areas (nourishment area 4 percent > north area and 2 percent > south area) (Table 8).

87. The mean depths of the false digs were not significantly different for the three areas in 1985 (overall mean, 29.7 cm) The turtles abandoned cavities up to a depth of 53.3 cm (range 7.6 to 53.3 cm), which is equal to the depth of the bottom of a completed cavity. A loggerhead sea turtle will usually dig a nest to a depth of 45.7 to 50.8 cm (Carr 1952). (The overall mean nest depth for the three areas in this study was 50.3 cm.) This shows that a turtle will abandon a cavity up to nest depth. Combined with the results of nest depth data (which showed no significant differences in nest depths between areas in the same year), the false dig depth and nest depth results suggest that a turtle will abandon a cavity if it cannot dig to a certain nest depth. One possible explanation is that nest depth is innately controlled and relative to the length of a turtle's hind flippers.

88. False digs in the nourished area were closer to the base of the dunes and farther from the wrack line than were digs in the two reference areas. The ratio of distance to wrack line to beach width was not significantly different for the three areas.

89. Shear resistance was significantly higher in project area false digs than in reference area false digs. Shear resistance was significantly higher in south false digs than in north false digs. This reflects the difference in shear resistance in the three areas; however, the mean shear resistance in each area for false digs was higher than shear resistance adjacent to nests in respective areas and depths. Since the turtles nest and reject cavities over a very wide range of shear resistances, it is not readily apparent at what shear resistance a turtle will reject a site. In the north, the beach was the softest, and turtles rejected sites with very low shear resistance (minimum, 60 cone index values). However, in at least two instances in the north area, turtles rejected sites that were impenetrable: one in which a turtle dug down into a sheet of plywood buried in the sand and the second in which it dug to bedrock (two digs). In another instance in the south area, a turtle dug to bedrock and then abandoned the site.

90. Many places in the project area could not be dug by hand and only with difficulty with a shovel; yet a turtle would dig a cavity and nest.

Turtles can dig in very hard substrates and will nest if it is possible for them to reach nest depth; however, they will reject a site with a soft consistency. One could reason that sites with a soft consistency were abandoned because of disturbance. Based on the presence of tracks, a dog seemed to have caused a cavity to be abandoned in one instance. However, this false dig and others with a crawl pattern indicating a disturbance were not included in the analysis (i.e., a very sharp turn or "v" pattern at the apex of the crawl may indicate disturbance) (Pritchard et al. 1983).

Turtle response to scarps

91. Nesting turtle response to the scarp was variable. Sometimes a turtle would crawl up to a scarp of 30 to 45 cm, turn around, and return to the water without nesting at that time (Figure 21). Sometimes the turtle would crawl up and over a scarp 1.2 m in height and nest (Figure 17).

Conclusions

Physical data

92. The following conclusions can be made regarding physical data:

- a. The renourished project beach had a harder consistency than did the two reference areas prior to renourishment and a harder consistency after nourishment than did the two reference areas and the prenourishment project beach.
- b. The project beach increased in compaction after nourishment, but the reference areas remained unchanged.
- c. Only slight differences were found in dry densities between areas. The areas did not differ among themselves from prenourishment to postnourishment. The project area was generally lower in density.
- d. No differences in the percentages of moisture content were found between the nourishment beach and the reference beaches.
- e. The sand in the project area shifted in percentage of medium and medium-fine grain sizes prenourishment to finer sizes after nourishment. The median and mean sand diameter in the project area became finer after nourishment.
- f. Although some changes in the percentages of flat grains occurred after nourishment, the changes do not appear to be such that they would have much effect on sand consistency. Grain orientation (beach structure) may be a more important factor to sand consistency than percentages of flat grains. A layering of sand grains appeared to have occurred in the renourished beach.

Figure 21. A scarp in the south reference area, Delray Beach, Florida, which a turtle encountered (false crawl) and then returned to the water

g. The cause of the harder consistency of Delray Beach after nourishment is not clear but appears to be a function of a shift to a finer grain size, layering of the sand grains parallel to the beach surface, the weight of sand-water slurry during pumping, compaction by equipment operating on the beach during nourishment, and possibly the cohesion of sand particles by the silt-clay fraction. These "causes" will require further investigation, including comparison with other nourished beaches.

Biological data

93. The following conclusions can be made regarding biological data:

a. Nests placed in aragonite, nourished sand, and natural sand in a hatchery resulted in the following: no effect of nourished sand on eggs or hatchlings, no effect of aragonite sand on eggs but a higher number of piped dead hatchlings, and no effect of natural sand on eggs but a slightly higher number of dead hatchlings in the nest.

b. The number of emergences in the project area decreased slightly (2.2 percent) from prenourishment (1984) to postnourishment (1985), but the number of nests per emergence decreased more substantially (13.0 percent). At the same time, the number of emergences in the reference areas appeared to increase, and the number of nests per emergence decreased only slightly.

c. Because of storms, nest predation, and loss of nest markers, only 10 out of 40 nests left in situ in the nourishment area

could be used in a comparison of nest parameters. None of the nest parameters (number of eggs, number of eggs hatched, number of eggs unhatched, hatch success, number of piped dead hatchlings, number of dead hatchlings, number of live hatchlings, and hatchling ratio) were significantly different for the nourished and north and south reference beaches in 1985.

d. A higher shear resistance was found adjacent to nests in the nourished area than in the reference areas. Turtle nests were found in sands with a range of consistencies from very soft to very hard (impenetrable with the penetrometer or by hand digging).

e. The distance to the bottom of the nest from the beach surface (nest depth) had little variation and was not affected by the harder consistency following nourishment. However, differences in the shape of some nests in the harder sand were observed.

f. Nests in the nourished beach were located relative to the wrack line (mean high high tide) even after the beach width was nearly doubled.

g. The number of false digs per 2,000 ft was lower in the nourished beach than in the two reference beaches; however, the number of false digs per excavation (nests plus false digs) was slightly higher for the nourished beach. Shear resistance was higher in false digs in the nourished sand and in the three areas than shear resistance adjacent to nests in the respective areas.

h. Scarping will occur following nourishment while the beach readjusts to a more natural beach profile. Turtle response to a beach scarp will vary from being blocked by a 30-cm scarp to scaling a scarp 1.2 m high. On public beaches, scarp formation is mediated by the sloping of the scarp by beach cleaning equipment.

Summary Conclusions

94. Delray Beach had a harder consistency from both previous nourishments and the 1984 renourishment. The cause of the harder consistency is unclear; however, finer grain size, layering of sand grains, the cohesion of silt-clay particles, equipment operation on the beach, and the weight of sand-water slurry from hydraulic pumping are probable contributors to a harder consistency. The overall effects of the nourishment on nesting sea turtles are as follows:

a. Eggs and hatchlings were not affected negatively by the nourished sand.

b. The nest depth and frequency of false digs may be affected by the harder consistency, but this occurrence was not evident in this study.

c. Nest shape and nest-digging time may be affected by sand consistency.

d. The number of nests per emergence appears to have declined following the nourishment.

e. Aragonite sand may negatively affect piping hatchlings.

f. A scarp may block some turtles from nesting, but some may scale the scarp, particularly if the scarp is sloped.

References

Bjorndal, K. A., Meylan, A. B., and Turner, F. J. 1983. "Sea Turtles Nesting at Melbourne Beach, Florida; I: Size, Growth, and Reproductive Biology," Biological Conservation, Vol 26, pp 65-77.

Caldwell, D. K. 1959. "The Loggerhead Turtles of Cape Romain, South Carolina," Bulletin of the Florida State Museum, Vol 4, No. 4, pp 320-348.

Caldwell, D. K., Carr, A., and Ogren, L. H. 1959. "Nesting and Migration of the Atlantic Loggerhead Turtle," Bulletin of the Florida State Museum, Vol 4, pp 295-308.

Carr, A. F. 1952. Handbook of Turtles: The Turtles of the United States, Canada, and Baja California, Comstock Publishing Association, Ithaca, New York.

__________. 1967. So Excellent a Fishe, Natural History Press, New York.

Coastal Engineering Research Center. 1984. Shore Protection Manual, Vols I and II, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Ehrhart, L. M. 1979. "Patterns of Sea Turtle Mortality on the East-Central Florida Coast, 1977-78," Florida Science, Vol 41, p 26.

Ehrhart, L. M., and Raymond, P. W. 1983. "The Effects of Beach Restoration on Marine Turtles' Nesting in South Brevard County, Florida," US Army Engineer District, Jacksonville, Jacksonville, Fla.

Fletemeyer, J. 1979. "Sea Turtle Monitoring Project," report to Broward County Environmental Quality Control Board, Broward County, Fla.

__________. 1981. "Sea Turtle Monitoring Project," report to Broward County Environmental Quality Control Board, Broward County, Fla.

__________. 1982. "Sea Turtle Monitoring Project," report to Broward County Environmental Quality Control Board, Broward County, Fla.

__________. 1983a. "Sea Turtle Monitoring Project," report to Broward County Environmental Quality Control Board, Broward County, Fla.

Fletemeyer, J. 1983b. "The Impact of Beach Renourishment on Sea Turtle Nesting (Abstract)," presented at 1983 meeting of the American Shore and Beach Preservation Association and The Florida Shore and Beach Preservation Association, Boca Raton, Fla.

Frazer, N. B. 1982. "Growth and Age at Maturity of Loggerhead Sea Turtles: Review and Prospectus," Marine Turtle Newsletter, Vol 22, pp 5-8.

Griffiths, J. C. 1967. Scientific Method in Analysis of Sediments, McGraw-Hill Book Company, New York.

Gutzke, W. H. N. 1984. "Modification of the Hydric Environment by Eggs of Snapping Turtles (*Cheldra serptina*)," Canadian Journal of Zoology, Vol 62, pp 2401-2403.

Hendrickson, J. R. 1958. "The Green Turtle, *Chelonia mydas* (Linn.), in Malaya and Sarnivak," Proceedings of the Zoological Society of London, Vol 130, pp 455-535.

Hopkins, S. R., and Richardson, J. I., eds. 1984. "Recovery Plan for Marine Turtles," US Department of Commerce, National Oceanic and Atmospheric Association, National Marine Fisheries Service, St. Petersburg, Fla.

Hughes, G. R. 1974. "The Sea Turtles of South-East Africa; I: Status, Morphology, and Distributions," Investigational Report No. 35, South African Association for Marine Biological Research, Durban, South Africa.

LeBuff, C. R., Jr. 1974. "Unusual Nesting Relocation in the Loggerhead Turtle, *Caretta caretta*," Herpetologica, Vol 30, No. 1, pp 20-31.

Limpus, C. J., Baker, V., and Miller, J. D. 1979. "Movement Induced Mortality of Loggerhead Eggs," Herpetologica, Vol 35, No. 4, pp 335-338.

Mann, T. M. 1978. "Impacts of Developed Coastline on Nesting and Hatchling Sea Turtles in Southeastern Florida," Florida Marine Research Publication, Vol 33, pp 53-55.

Means, R. E., and Parcher, J. V. 1963. Physical Properties of Soils, Charles E. Merrill Books, Inc., Columbus, Ohio.

Nelson, D. A. 1986. "Pilot Study on the Use of Tilling to Soften Sand Consistency After Beach Nourishment," Draft Report, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Nelson, D. A., and Mayes, C. H. 1986. "St. Lucie Inlet Dredged Material Disposal Effects on the Firmness of Sand Used by Nesting Turtles," Draft Report, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Pritchard, P., et al. 1983. Manual of Sea Turtle Research and Conservation Techniques, 2nd ed. K. A. Bjorndal and G. H. Balazs, eds., Center for Environmental Education, Washington, DC.

Richardson, J. I., and Richardson, T. H. 1982. "An Experimental Population Model for the Loggerhead Sea Turtle (*Caretta caretta*)," Biology and Conservation of Sea Turtles, K. A. Bjorndal, ed., Smithsonian Institution, Washington, DC.

SAS Institute, Inc. 1985. Statistical Analysis System, Cary, N. C.

Stoneburner, D. L. 1981. "Summary of the Loggerhead Sea Turtle Research Project Coordinated at Canaveral National Seashore, Cumberland Island National Seashore, Cape Lookout National Seashore: A Final Report," Research/Resources Management Report, Vol 39, US Department of the Interior, National Park Service, Atlanta, Ga.

_________. 1982. "Satellite Telemetry of Loggerhead Sea Turtle Movement in the Georgia Bight," Copeia, Vol 1982, No. 2, pp 400-408.

Stoneburner, D. L., and Richardson, J. I. 1981. "Observation on the Role of Temperature in Loggerhead Turtle Nest Site Selection," Copeia, Vol 1981, No. 1, pp 233-241.

Strock, A. V., and Associates, Inc. 1984. "Second Periodic Nourishment, Delray Beach, Florida," General Design Memorandum, Deerfield Beach, Fla.

Talbert, O. R., Jr., et al. 1980. "Nesting Activity of the Loggerhead Turtle (*Caretta caretta*) in South Carolina; I: A Rookery in Transition," Copeia, Vol 1980, No. 4, pp 709-718.

US Army Corps of Engineers. 1970. "Laboratory Soils Testing," Engineering Manual EM 1110-2-1906, Washington, DC.

US Army Engineer Waterways Experiment Station. 1983. "Handbook for Concrete and Cement," Technical Report CRD C-120-55, Vicksburg, Miss.

Williams-Walls, N., et al. 1983. "Spatial and Temporal Trends of Sea Turtle Nesting on Hutchinson Island, Florida, 1971-1979," Bulletin of Marine Science, Vol 23, No. 1, pp 55-66.

Appendix A: Parameters for Turtle Nests, Delray Beach, Florida, 1984 and 1985

Variable*	N	Mean	Standard Deviation	Minimum Value	Maximum Value	Std Error of Mean	Sum	Variance	C.V.
				North Reference Area, 1984					
DHT	76	37.57	18.78	2.00	85.00	2.15	2855.00	352.70	49.99
DVEG	74	35.77	27.14	-25.00	140.00	3.15	2647.00	736.45	75.86
PENE6	15	60.20	22.82	40.00	110.00	5.89	903.00	520.50	37.90
PENE12	15	126.40	74.52	60.00	370.00	19.24	1896.00	5552.97	58.95
PENE18	15	232.47	121.45	100.00	600.00	31.36	3487.00	14751.27	52.24
RATIO1	74	0.54	0.30	0.03	1.50	0.03	40.03	0.09	55.20
NESTDEP	67	19.57	1.66	16.00	24.00	0.20	1311.00	2.76	8.49
INCPER	43	53.72	3.30	46.00	64.00	0.50	2310.00	10.87	6.13
#EGGS	76	118.36	18.26	80.00	160.00	2.09	8995.00	333.24	15.42
#HATCHD	66	105.80	22.15	9.00	146.00	2.72	6983.00	490.68	20.93
#UNHACH	66	9.79	8.72	0.00	39.00	1.07	646.00	76.11	89.13
PIPDEAD	65	0.60	1.72	0.00	11.00	0.21	39.00	2.96	286.86
TURDEAD	65	0.54	2.35	0.00	18.00	0.29	35.00	5.53	436.86
HATCHLNG	65	106.75	18.82	67.00	146.00	2.33	6939.00	354.03	17.62
RATIO2	66	0.90	0.13	0.08	1.00	0.02	59.17	0.02	14.29
RATIO3	65	0.90	0.03	0.63	1.00	0.01	58.81	0.01	9.11
				North Reference Area, 1985					
DHT	153	30.67	15.01	0.00	88.00	1.30	4692.00	256.50	52.22
DVEG	153	46.16	21.78	0.00	110.00	1.75	7064.00	474.41	47.17
PENE6	166	86.96	36.45	26.67	210.00	2.83	14435.00	1328.52	41.91
PENE12	166	141.63	69.78	30.00	473.33	5.42	23512.00	4869.93	49.27
PENE18	165	213.88	122.24	46.67	566.67	9.52	35290.00	14942.18	57.15
RATIO1	153	0.41	0.20	0.00	1.00	0.02	62.36	0.03	48.00
NESTDEP	40	20.30	1.57	18.00	24.00	0.25	812.00	2.47	7.74
INCPER	48	54.0	1.88	50.00	58.00	0.27	2593.00	3.55	3.49
#EGGS	63	110.75	17.38	63.00	154.00	2.19	6977.00	301.93	15.69
#HATCHD	38	97.92	20.33	49.00	141.00	3.30	3721.00	413.32	20.76
#UNHACH	38	11.16	13.47	1.00	56.00	2.19	424.00	181.49	120.73
PIPDEAD	38	0.89	3.91	0.00	24.00	0.53	34.00	15.29	436.96
TURDEAD	38	0.42	1.27	0.00	7.00	0.21	16.00	1.60	300.57
HATCHLNG	38	97.50	20.29	49.00	141.00	3.29	3705.00	411.61	20.80
RATIO2	38	0.189	0.12	0.48	0.99	0.02	33.99	0.01	13.20
RATIO3	38	0.89	0.12	0.48	0.99	0.02	33.83	0.01	13.13
				Project Area, 1984					
DHT	220	34.77	21.37	0.00	115.00	1.44	7649.00	456.54	61.45
DVEG	219	50.79	32.40	-50.00	146.00	2.19	11123.00	1049.73	63.79
PENE6	56	91.03	60.13	23.00	350.00	8.04	5098.00	3616.00	66.05
PENE12	56	240.95	163.93	57.00	999.00	21.90	13493.00	26872.41	68.03
PENE18	56	394.23	221.41	97.00	999.00	29.59	22077.00	49021.12	56.16
RATIO1	219	0.44	0.30	0.00	1.77	0.02	96.19	0.09	67.28
NESTDEP	205	20.08	1.92	15.00	26.00	0.13	4113.00	3.70	9.57
#EGGS	221	113.47	20.87	49.00	163.00	1.40	25077.00	435.50	18.39

(Continued)

Variable*	N	Mean	Standard Deviation	Minimum Value	Maximum Value	Std Error of Mean	Sum	Variance	C.V.
				Project Area, 1985					
DHT	140	28.47	20.46	0.00	144.00	1.73	3986.00	418.43	71.84
DVEG	139	113.29	44.34	0.00	350.00	3.76	15748.00	1966.41	39.14
PENE6	142	231.43	118.31	50.00	673.00	9.93	32862.67	13997.91	51.12
PENE12	142	406.15	210.76	40.00	999.00	17.68	57673.00	44375.32	51.86
PENE18	140	596.97	248.20	80.00	999.00	20.98	83568.33	61601.55	41.58
RATIO1	139	0.22	0.17	0.00	1.00	0.01	30.03	0.02	76.79
NESTDEP	56	19.84	1.94	16.00	25.00	0.26	1111.00	3.77	9.79
INCPER	18	52.50	1.62	50.00	55.00	0.38	945.00	2.62	3.08
#EGGS	22	110.09	20.25	70.00	150.00	4.32	2422.00	409.90	18.39
#HATCHD	10	91.90	22.17	57.00	127.00	7.01	919.00	491.66	24.12
#UNHACH	10	17.10	10.63	2.00	38.00	3.36	171.00	112.99	62.16
PIPDEAD	10	0.30	0.67	0.00	2.00	0.21	3.00	0.46	224.98
TURDEAD	10	1.30	2.50	0.00	8.00	0.77	13.00	6.23	192.05
HATCHLNG	10	90.60	21.93	57.00	125.00	6.93	906.00	480.93	24.20
RATIO2	10	0.84	0.09	0.70	0.98	0.03	8.42	0.01	11.00
RATIO3	10	0.83	0.10	0.68	0.98	0.03	8.31	0.01	11.98
				South Reference Area, 1984					
DHT	103	41.65	17.65	5.00	85.00	1.73	4290.00	311.36	42.36
DVEG	102	35.55	22.63	-10.00	80.00	2.24	3626.00	512.17	63.66
PENE1	26	96.62	53.55	40.00	250.00	10.50	2512.00	2867.13	55.42
PENE2	26	227.15	86.86	50.00	367.00	17.03	5906.00	7544.13	38.23
PENE3	25	359.48	150.95	70.00	650.00	30.19	8987.00	22785.01	41.99
RATIO1	102	0.56	0.27	0.08	1.15	0.03	56.94	0.07	48.80
NESTDEP	77	19.22	1.62	16.00	24.00	0.18	1480.00	2.62	8.42
INCPER	71	53.54	3.36	45.00	68.00	0.40	3801.00	11.31	6.28
#EGGS	101	116.56	17.09	72.00	161.00	1.70	11773.00	292.07	14.66
#HATCHD	101	106.07	20.08	24.00	158.00	2.00	10713.00	403.27	18.93
#UNHACH	100	9.38	8.53	0.00	43.00	0.85	938.00	72.78	90.95
PIPDEAD	100	0.70	1.81	0.00	12.00	0.18	70.00	3.28	258.83
TURDEAD	100	1.48	4.67	0.00	40.00	0.47	148.00	21.78	315.23
HATCHLNG	100	105.41	18.38	68.00	158.00	1.84	10541.00	337.84	17.43
RATIO2	100	0.91	0.07	0.62	1.00	0.01	91.37	0.01	8.20
RATIO3	100	0.90	0.08	0.62	1.00	0.01	90.15	0.01	8.92
				South Reference Area, 1985					
DHT	185	34.49	20.02	0.00	99.00	1.47	6381.00	400.66	58.03
DVEG	184	34.89	23.41	0.00	135.00	1.73	6419.00	548.10	67.10
PENE1	198	167.06	54.82	13.33	353.33	3.90	33078.00	3005.68	32.81
PENE2	198	295.12	106.17	50.00	600.00	7.55	58433.67	11272.16	35.97
PENE3	198	465.76	179.44	53.33	999.00	12.75	92220.33	32198.56	38.52
RATIO1	184	0.51	0.27	0.00	1.00	0.02	93.42	0.07	53.35
NESTDEP	61	19.85	1.65	17.00	24.00	0.21	1211.00	2.73	8.32
INCPER	73	52.59	2.05	47.00	58.00	0.24	3839.00	4.19	3.89
#EGGS	93	109.12	19.23	53.00	157.00	1.99	10148.00	369.65	17.62
#HATCHD	64	95.88	20.10	8.00	133.00	2.51	6136.00	403.86	20.96
#UNHACH	64	12.09	12.59	1.00	82.00	1.57	774.00	158.56	104.12
PIPDEAD	64	1.73	7.17	0.00	44.00	0.90	111.00	51.37	413.26
TURDEAD	64	0.70	2.08	0.00	14.00	0.26	45.00	4.34	296.25
HATCHLNG	64	95.17	20.09	7.00	133.00	2.51	6091.00	403.67	21.11
RATIO2	64	0.87	0.14	0.07	0.99	0.02	55.41	0.02	16.70
RATIO3	64	0.86	0.15	0.06	0.99	0.02	55.01	0.02	17.03

(Continued)

Appendix A: (Concluded)

*DHT = distance of nest to the wrack line (ft)
DVEG = distance of nest to the base of the dune (ft)
PENE6 = shear resistance adjacent to the nest at the 6-in. depth (lb/sq in.)
PENE12 = shear resistance adjacent to the nest at the 12-in. depth (lb/sq in.)
PENE18 = shear resistance adjacent to the nest at the 18-in. depth (lb/sq in.)
RATIO1 = distance of nest to wrack line relative to beach width
#EGGS = number of eggs per nest
#HATCHD = number of eggs hatched per nest
#UNHACH = number of eggs unhatched per nest
PIPDEAD = number of piped dead hatchlings per nest (still in shell)
TURDEAD = number of dead hatchlings per nest (out of shell)
HATCHLNG = number of live hatchling per nest
RATIO2 = number of eggs hatched per nest to number of eggs per nest (hatch success)
RATIO3 = number of live hatchlings to number of eggs per nest (hatchling ratio)

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